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OFFICE OF NAVAL RESEARCH  
TECHNICAL REPORT

for

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Contract N00014-90-J-4141

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Fundamental Properties and Device Applications of  
 $Ge_xSi_{1-x}/Si$  superlattices  
(Supplemental)

Principal Investigator: Professor Kang L. Wang  
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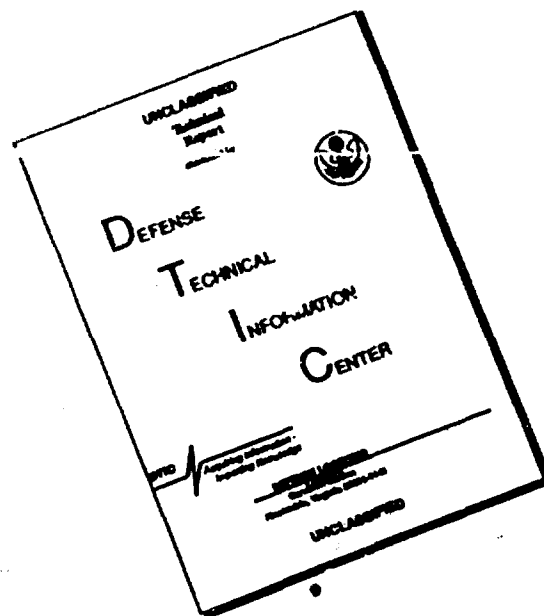
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## Fundamental Properties and Device Application of Ge/Si Superlattices

Contract Number N0014-89-J3227

Principal Investigator: Kang L. Wang

### Description of Work:

The objectives of this contract is to expand the work on the current ONR supported research in the study of  $Ge_xSi_{1-x}/Si$  superlattice and quantum well structures into the electromagnetic wave generation and detection applications. The control parameters such as the band offsets as well as the strain induced critical thickness limitation will be investigated. The band-gap engineered superlattices and quantum structures will be designed for tunable frequency detector applications and studied for their strain induced electrical characteristics.

### Approach:

Devices to be considered for this study are based on the concept of the band-gap engineering. In the case of Si-Ge heterosystem, strain induced tunability adds a new degree of freedom on the structure design. The effect of strain on the critical thickness limitation and the band offset is investigated. Resonant tunneling diodes with several different structure, grown at low temperature are studied by tunneling spectroscopy.

### Progress:

The dependence of the pseudomorphic thickness of strained  $Ge_xSi_{1-x}$  layers on the growth temperature and the growth pressure are extensively studied. Very thick coherently strained  $Ge_xSi_{1-x}$  layers are successfully grown at low temperatures. After growth, the samples are characterized by Rutherford backscattering spectroscopy and X-ray rocking curve techniques for the structure controlability. In addition, the I-V-T method is employed to determine the valence band discontinuity  $\Delta E_v$  in the coherently strained  $Ge_xSi_{1-x}/Si$  heterostructures. The results obtained are in good agreement with the theoretical calculations by pseudopotential method. The microwave time of flight set-up have been completed and microwave mobility measurement of the Si-Ge alloys are in progress.

Publication:

Khorram, S., Chern, C.H., and Wang, K.L., "Measurement of Valence Band Offset In Strained  $Ge_xSi_{1-x}/Si$  Heterojunctions", MRS Spring Meeting, Anaheim, California 1991.(ONR, SRC)

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# ABSTRACT 1991 SPRING MEETING

Submitted to: Symposium B  
Symposium Title: Silicon Molecular Beam Epitaxy

MEASUREMENT OF VALENCE BAND OFFSET IN STRAINED  $\text{Ge}_x\text{Si}_{1-x}/\text{Si}$  HETEROJUNCTIONS. S. Khorram, C. H. Chern, and K. L. Wang, Device Research Laboratory, 7619 Boelter Hall, UCLA, Los Angeles, CA.

The valence band discontinuity  $\Delta E_v$  in the coherently strained  $\text{Ge}_x\text{Si}_{1-x}/\text{Si}$  heterostructures is determined using I-V-T measurement. Previously, band offsets have been determined using XPS. The electrical measurements are difficult due to the thin layer imposed by the strain. Recently, low temperature growth of thick layers ( $>1000 \text{ \AA}$ ) of coherently strained  $\text{Ge}_x\text{Si}_{1-x}$  on Si has been achieved and thus made it possible for an accurate electrical measurement of band offset.

These samples are grown at  $350^\circ\text{C}$ , on  $(100) p^+ \text{Si}$  substrate. The structure consists of  $3000 \text{ \AA}$  p-type Si buffer layer, followed by  $600\text{-}1000 \text{ \AA}$  of undoped Si layer, and capped by a p-type strained  $\text{Ge}_x\text{Si}_{1-x}$  layer. Depending on Ge concentration,  $x$ , the thickness of the strained  $\text{Ge}_x\text{Si}_{1-x}$  layer is varied from  $1000\text{-}3000 \text{ \AA}$ . In order to avoid complications associated with the heavily doped semiconductors, the layers are chosen to be lightly doped. The crystallinity and the quality of these layers have been verified using x-ray rocking curve technique. Due to high metastability of these structures, exposure to extreme temperatures or rapid temperature variations are avoided.

The I-V measurement is done for mesa structures of various Ge concentrations at temperatures between  $77^\circ\text{K}$  to  $300^\circ\text{K}$ . The electrical measurements of the band discontinuity, in principle provide better accuracy than XPS. Typically, for the  $\text{Ge}_{0.3}\text{Si}_{0.7}$  and the  $\text{Ge}_{0.5}\text{Si}_{0.5}$  structures used in this experiment, the valence band discontinuity are measured to be  $250 \pm 15 \text{ meV}$  and  $330 \pm 20 \text{ meV}$ , respectively. These results are in good agreement with the theoretical calculations of Van der Walle.

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# MEASUREMENT OF VALENCE BAND OFFSET IN STRAINED $\text{Ge}_x\text{Si}_{1-x}/\text{Si}$ HETEROJUNCTIONS

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## ABSTRACT

The valence band discontinuity  $\Delta E_v$  in the coherently strained  $\text{Ge}_x\text{Si}_{1-x}/\text{Si}$  heterostructure is determined using I-V-T measurement. The electrical measurements of the band discontinuity of the pseudomorphic layers are difficult due to the thin layer imposed by the strain. Recently, low temperature growth of thick layer ( $>1000 \text{ \AA}$ ) of coherently strained  $\text{Ge}_x\text{Si}_{1-x}$  on Si has been achieved and thus made it possible for an accurate electrical measurement of band offset. The results obtained are in good agreement with the theoretical calculations by pseudopotential method.

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- a. Number of Papers Submitted to Referred Journal but not yet published: 0
- b. Number of Papers Published in Referred Journals: 1  
(list attached)
- c. Number of Books or Chapters Submitted but not yet Published: 0
- d. Number of Books or Chapters Published: 0  
(list attached)
- e. Number of Printed Technical Report & Non-Referred Papers: 0  
(list attached)
- f. Number of Patents Filed: 0
- g. Number of Patents Granted: 0  
(list attached)
- h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 0
- i. Number of Presentation at Workshop or Prof. Society Meetings: 1
- j. Honors/Awards/Prizes for Contract/Grant Employees:  
(list attached, this might include Scientific Soc. Awards/Offices.  
Promotions, Faculty Award/Offices etc.) 0
- k. Total number of Graduate Students and Post-Docs Supported at least 25% this  
year on this contract, grant:  
Grad Students 1 and Post Docs 0

How many of each are females or minorities?  
(These 6 numbers are for ONR's EEO/Minority  
Reports; minorities include Blacks, Aleuts  
Amindians, etc and those of Hispanic or  
Asian extraction/nationality. This Asians  
are singled out to facilitate meeting the  
varying report semantics re "under-  
represented")

[	Grad Student Female	<u>1</u>
]		
[	Grad Student Minority	<u>0</u>
]		
[	Grad Student Asian e/n	<u>0</u>
]		
[	Post-Doc Female	<u>0</u>
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[	Post-Doc Minority	<u>0</u>
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[	Post-Doc Asian e/n	<u>    </u>
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